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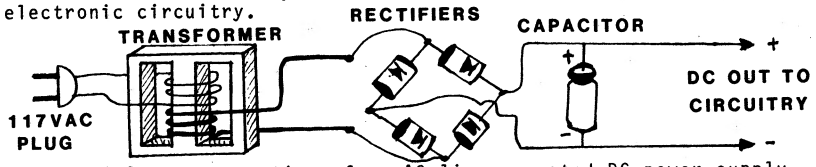
cheap 'n easy...

DC POWER SUPPLIES VOL 1

HOW TO BUILD A DC POWER SUPPLY FOR YOUR ELECTRONIC PROJECT...

Most electronic circuits are alike in one respect: They need a DC power source to run them. Small, simple circuitry can be powered by batteries, but usually a permanent power source is desired... one that plugs into a wall outlet and won't run down. This information sheet will tell you how to build a power supply for most electronic circuitry.



A pictorial representation of an AC line-operated DC power supply is drawn above. The supply has three components: A transformer, which converts the line voltage to the voltage needed, an array of rectifiers, which change the AC voltage to DC, and a filter capacitor.

TRANSFORMERS

A transformer consists of two coils of wire wound around a common magnetic core. Due to the magnetic action between the windings and core, an AC voltage applied to the input (primary) winding will cause an AC voltage to appear across the output (secondary) winding. The ratio of input to output voltage is determined by the ratio of the number of turns of wire in the two windings.

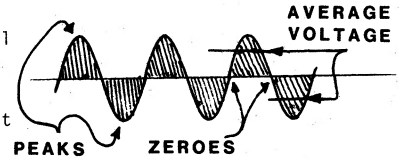
The transformer serves two functions. First, it changes the 117 volts of the power line to the voltage required by the circuitry. Second, it isolates the circuitry from the AC power line to lessen the possibility of electrical shock.

Things to remember about transformers:

1. A transformer works ONLY with AC power. It will not function with DC. In practice this is of little concern; nowadays most power lines are AC, because the power company uses transformers too.

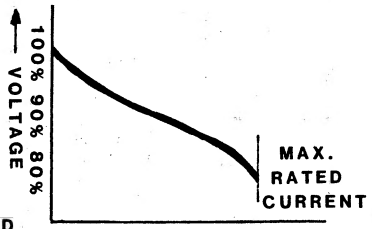
2. AC, or alternating current, means that the current reverses direction twice each cycle. (U.S. power lines operate at 60 Cycles Per Second or 60 Hertz, abbreviated 60Hz.) This means that twice each cycle the voltage is, for an instant, zero. Also, twice each cycle the voltage reaches a peak that is about 1.4 time its nominal value. Thus a 50 volt AC source will actually reach 70 volts (1.4 X 50) twice each cycle. This is important because, as

explained below, a DC power supply will put out a higher voltage than the transformer that is driving it.

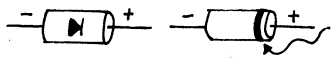


On the other hand, a DC supply will not be able to put out as much current as the transformer is rated for. This is due to the fact that it is being expected to put out a higher voltage, and also because the load on the transformer is concentrated at the voltage peaks that occur twice each cycle. A good estimate is that a DC supply can put out half as much current as the transformer is rated for. Example: A transformer rated at 50 volts at 4 amps will produce, in a DC supply, 70 volts at 2 amps.

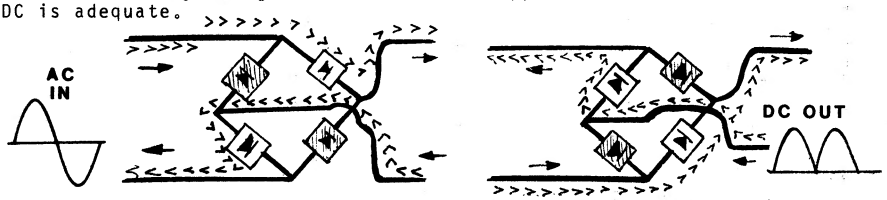
3. There are losses in a transformer which will cause the output voltage to sag as more current is drawn. Your design should take into account both the transformer output when it is driving no load, and when it is driving the maximum expected load. The "maximum load" output must still be high enough in voltage to operate the circuitry properly; the "no load" voltage should not be so high that it may damage the circuit.



RECTIFIERS



Once the transformer has isolated and converted the 117 volt power to a value suitable for the circuitry, the AC voltage must be changed to DC. This is done my means of rectifiers, which electrically act like one-way valves. When four rectifiers (also called diodes) are arranged as in the drawing, they channel the current flow so it's always going in the same direction. It's still uneven DC - zero volts twice each cycle, 1.4 times nominal twice each cycle - but it is DC. For battery chargers and some other applications, this unfiltered DC is adequate.



Things to remember about rectifiers:

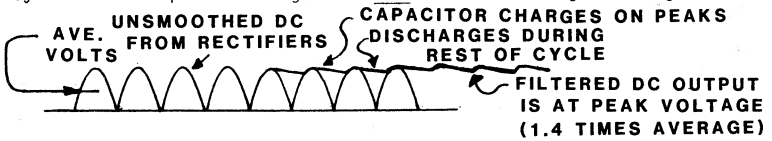
1. They're one-way valves, and which way you connect them is critical. If you connect even one of the rectifiers in the drawing backwards, you will create a direct short circuit across the transformer output.

2. Rectifiers have maximum voltage and current ratings. Choose ones which will withstand the maximum expected voltage - that is, 1.4 times the rated output of the transformer - and the maximum expected load current.

3. There is an approximate 0.7 volt drop across a rectifier. Since at any instant there are two rectifiers in series with the load, 1.4 volts should be subtracted from the expected output voltage. This factor is important when designing low-voltage power supplies.

CAPACITORS

Most electronic circuitry needs smooth DC to operate. The first step in filtering out the lumps in the DC as it leaves the rectifiers is to connect a filter capacitor as shown in the diagram. A capacitor is a storage device that charges up on voltage peaks and then discharges during the two times each cycle when the transformer-rectifier combination is putting out no voltage. A properly sized capacitor will have enough storage to supply the power to the load circuit during these times. The capacitor will charge up during its charging cycle to the peak voltage and not to the average voltage.


AVE. VOLTS
UNSMOOTHED DC FROM RECTIFIERS
CAPACITOR CHARGES ON PEAKS
DISCHARGES DURING REST OF CYCLE
FILTERED DC OUTPUT IS AT PEAK VOLTAGE (1.4 TIMES AVERAGE)

Things to remember about capacitors:

1. Like rectifiers, they will self-destruct if you hook them up backwards. the + and - terminals are marked on the terminals or the capacitor body, either with polarity signs or colors (Red is + and Black is -).

2. Choose a capacitor with a voltage rating equal to or greater than the peak output of the transformer.

3. The bigger the capacitor (rated in microfarads, Mfd or ufd) the better the filtering, but after a certain point it doesn't pay to add capacitance. More sophisticated techniques are called for.

DESIGNING THE POWER SUPPLY

Since the end product is what counts, design is done backwards. Start with the voltage and current requirements. Let us assume we are building a supply that is needed to power a circuit requiring 20 volts at one amp. Let us also assume that the load current varies between zero and one amp and that significant overvoltage (say, 25 volts) will not impair the operation of the circuit or damage its components.

1. Choose the capacitor. A good rule is to use 1000 - 2000 MFD per amp of expected load current. Voltage should be greater than the maximum expected voltage, which will be more than 20 volts. 1500 or greater MFD at 30 volts or greater would be adequate.

2. Choose rectifiers. Here again, anything over 30 volts and 1 amp is okay. 50 volt, 1 amp rectifiers are widely available.

3. Choose the transformer. If we want an output of 20 volts or so, at 1 amp, and if we ignore the voltage drop across the rectifiers, then we want a transformer that puts out voltage peaks of 20 volts. Since

the peak output is 1.4 times the average output, divide 20 by 1.4 to get 14 volts. So you need a transformer that puts out 14 volts; maybe 15, to be safe, since we are working with a circuit that will withstand considerable overvoltage.

Now, remember that you can only expect about half as much current out of a DC supply as the transformer is rated to deliver AC. So, the transformer must be able to put out 2 amps at 15 volts for us to get a supply that delivers 1 amp at 20 volts.

So we need: A transformer that delivers 15 volts at 2 amps, four rectifiers capable of handling at least 30 volts at 1 amp, and a filter capacitor that is at least 1500MFD and at least 30 volts.

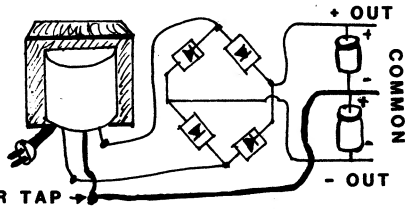
DESIGNING THE POWER SUPPLY THE SIMPLIFIED ACME WAY

If you are using a transformer bought from ACME, most of this calculation is unnecessary, since we have already specified the AC and DC output of our transformers at two different load currents and at no load, along with a suitable capacitor to use in DC supplies. Simply pick up the parts and put it together.

FURTHER REFINEMENTS

1. BETTER FILTERING: Many circuits require better filtering or more closely regulated voltage than the simple power supply outlined here will provide. This calls for more sophisticated filtering and regulation techniques, which are beyond the scope of this article. Prepackaged solid state regulators are available which do a good job and which have directions for use supplied with the part. You will need to start with a power supply built as described here, but with an output several volts higher than you want the final regulated output to be; this will give the regulator a margin to work with.

2. DUAL VOLTAGE SUPPLIES: Many circuits require equal positive and negative voltages, such as ±10V with respect to a common. You could build up two power supplies, or choose a transformer with a center tap which has a total rated DC (not AC) output equal to the total voltage needed (in this case 20V) and connect it as shown.



3. FUSES: A fuse or circuit breaker in the power line is a very good idea. Its current rating is figured through a computation of the number of watts the circuitry draws. 1) Multiply the voltage your electronic circuitry runs on times the current it draws. This is the power it consumes. Example: A circuit that draws 1.5 amps at 20 volts uses 30 watts. 2) That same power, 30 watts, is drawn from the power line. Divide the wattage figure by the power line voltage to get the number of amps. Example: 30 watts divided by 120 volts is 1/4 amp. 3) Choose a fuse or circuit breaker that gives you a little leeway; in this case 1/2 amp would be suitable.

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DC POWER SUPPLIES VOL. 2

HOW TO IMPROVE THE DC POWER SUPPLY DESCRIBED IN VOLUME 1...

At the end of volume 1 of this series, we mentioned that many electronic circuits require better power supply filtering or regulation than the simple power supplies in volume 1 could provide. Volume 2 covers this additional material. To build an improved power supply, start with a basic supply as described in volume 1.

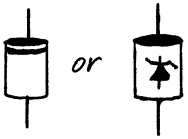
IMPORTANT: The filters and regulators described below lose a few volts, so you must start with a basic power supply that delivers 3-5 volts more, at full load, than the regulated output voltage you will want to wind up with.

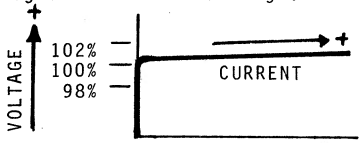
THE ZENER DIODE

The basis of most regulator circuits is the zener diode. It is similar to the usual rectifier or diode described in volume 1, with one difference: current will also flow in the reverse direction through a zener diode. This will happen, however, only if the voltage across the diode is above a certain threshold voltage. It is this threshold that makes the zener useful as a regulator.

It is useful to think of the analogy of a water glass. If you fill it to a certain level less than full, no water will flow out. However, if you try to fill it higher than the brim, excess water will spill over the top. The faster you pour in the water, the faster it spills out. In this way, the glass represents a regulating device: no matter how much or how little extra water you pour in, the water level in the glass stays right at the top.

Translating this into electronic terms, the water level in the glass represents voltage and spillage represents current. As shown in the graph at right below, the zener conducts no current at all until its threshold voltage is reached. Above that point, the current flow increases very rapidly as you try to apply more voltage. It is not incorrect to say that the zener "shorts out" the extra voltage by drawing whatever current is necessary to load it down to the zener's designed threshold voltage.





Things to remember about zener diodes:

1. Like other diodes, it is important which way you hook a zener up. In one direction, the current flow is impeded only by the normal .7 volt drop across a conducting diode. Zeners are used connected the other way.

2. Because the current flow increases very rapidly as you try to increase the voltage above the zener threshold, a means must be provided to insure that the maximum current available is not sufficient to destroy the diode. The current conducted by the zener is burned up as heat; there is a power limit specified by the manufacterer of the zener diode which must not be exceeded or the device will overheat and be destroyed.

3. At or near its maximum specified power, a zener diode will get quite hot. It must either be placed away from heat-sensitive components, or a larger zener must be used.

THE RESISTOR

A resistor, as its name implies, impedes current flow. This allows it to be used as the current-limiting device needed to prevent destruction of the zener diode.

Things to remember about resistors:

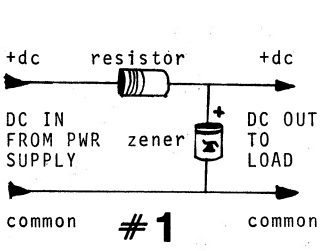
1. Resistors do not have a "right" and "wrong" direction.

2. Like a zener diode, a resistor has a specified power handling capability which must not be exceeded, and at or near this limit the resistor gets quite hot.

CHEAP 'N EASY REGULATOR #1:

Below left is shown a very simple regulating circuit. The DC input is from a basic power supply of the type described in volume 1. It should be capable of supplying 3 to 5, but not more than 7, volts of output more than the regulated voltage you want.

In this regulator, current flows through the resistor to the diode and the load circuit. The zener shunts to common any of the current passing through the resistor that the load circuit doesn't use. In this way, the zener maintains a nearly constant output voltage.



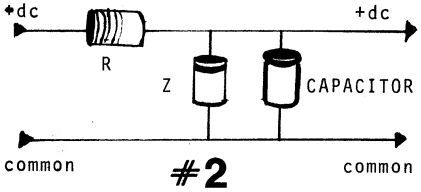
FOR ANY VOLTAGE IN THIS RANGE	AT ANY CURRENT IN THIS RANGE	USE ZENER OF DESIRED VOLTAGE AND WITH THIS POWER RATING:	USE RESISTOR OF THIS RESISTANCE AND THIS POWER RATING:
3-12V	0-20ma	1/2watt	150ohm,1/2w
12-25V	0-20ma	1watt	150ohm,1/2w
25-40V	0-20ma	2watt	150ohm,1/2w
3-12V	20-50ma	1watt	56ohm,1w
12-25V	20-50ma	2watt	56ohm,1w
3-12V	50-100ma	2watt	33ohm,2w

(The term "ma" means "thousandths of an amp". 20ma = .02 amp.)

CHEAP 'N EASY REGULATOR #2

Slightly better filtering can be achieved by adding a capacitor to filter #1. There is, after all, a slight change of voltage output with current change through the zener, and this will happen both as a result of the small amount

of ripple coming from the power supply and because of instantaneous change in the current demands of the load circuit. If this is a problem (the ripple, for example, means hum in an audio circuit) the addition of a capacitor, as shown below, will smooth out these instantaneous variations. (The capacitor will not improve the stability of the average voltage.)



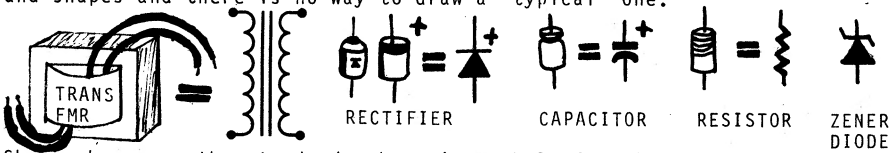
FOR A POWER SUPPLY OF ANY VOLTAGE, AT THE FOLLOWING CURRENT:	USE CAPACITOR OF RATED VOLTAGE EQUAL OR GREATER, OF THE FOLLOWING CAPACITY:
0-20ma	200mfd
20-50ma	500mfd
50-100ma	1,000mfd

The specified capacitors will give good filtering for low-level audio equipment and similar circuits, assuming that the power supply is properly constructed to begin with. Values of capacitance are very non-critical. Remember to observe the capacitor's polarity.

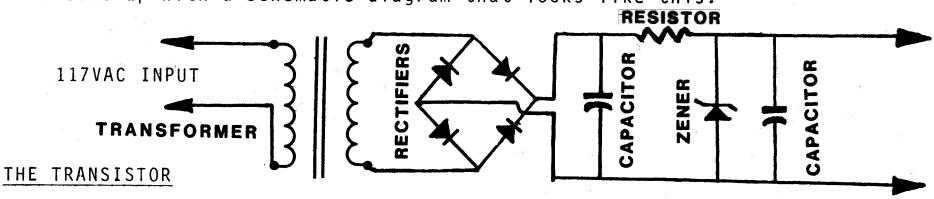
The simple regulators #1 and #2 have very serious limitations, but for low current applications in the current ranges shown, they are adequate and are widely used. The problem with higher current regulators is that the resistor must pass all the current the load circuit will ever use, and the zener must burn up all of that current that the load isn't using at any given moment. This wastefulness is no problem at low power levels, but for higher power supplies it is better to derive the regulated voltage from a low current regulator such as #1 or #2, and then add a current amplifier. A current amplifier, in more familiar terminology, is a transistor.

TIME OUT: READING SCHEMATIC DIAGRAMS

Up to this point, all diagrams have been drawn with actual pictures of the components used. This is never done in the "real world" of electronics; it's much faster to draw standard, simple symbols. At this point, we have to convert to symbolic drawings anyway, since transistors come in all sizes and shapes and there is no way to draw a "typical" one.

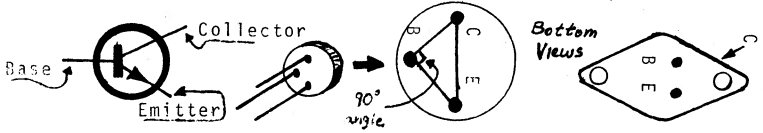


Shown above are the standard schematic symbols for all the parts we've used so far. Redrawing a complete power supply using regulator #2, we will come up with a schematic diagram that looks like this:



THE TRANSISTOR

The schematic symbol for a transistor is shown at left below. The three letters stand for the standard designations for its three terminals: Emitter, Base, and Collector. Shown to the right of the schematic are several common styles of transistor, with the connections identified. It is absolutely essential that you know (or, if a transistor doesn't look like one of these, that you find out from the manufacturer's literature) which is which.



The great benefit of the transistor is that it allows relatively small regulating components to control relatively large output current. The only power "burned up" in the circuit is that needed to drop the output voltage of the basic supply down to the regulated voltage required by the load. This can amount to a lot of power, and can generate a lot of heat, but still it's much more efficient than regulators 1 and 2.

Things to remember about transistors:

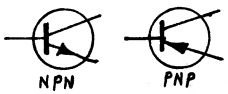
1. Transistors must be hooked up with attention to which terminal is which.

2. Transistors come in both "sexes"; the direction of the arrow indicates which is which. NPN transistors will be used in our cheap 'n easy regulators for power supplies where the negative is common; PNP transistors are for the reverse case. Be sure the transistor you select is the right kind.

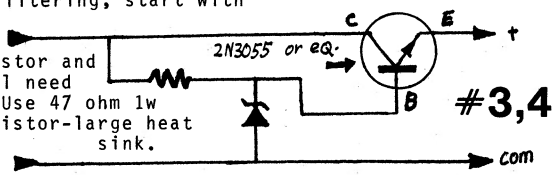
3. Every power transistor has a specified power limit, and higher power transistors can generate more heat than their radiating area can handle. This requires the attachment of external heat-radiating fins, or heat sinks. When attaching heat sinks, remember that the entire heat sink is usually connected to the +dc supply through the transistor. If this is unacceptable, insulating assemblies are available which will insulate the transistor electrically but still pass the heat to the heat sink.

4. Inherent in the construction of a transistor is a diode between the base and emitter; this means the actual output voltage will be .7 volt lower than the reference voltage connected to the base.

CHEAP 'N EASY REGULATOR #3



This one's really easy: Take regulator #1 and add a transistor. For additional filtering, start with regulator #2 instead.

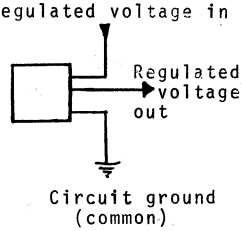


.1-.5A: Use 150 ohm 1/2w resistor and 1 watt zener. Transistor will need small heat sink. / .5-1.5A: Use 47 ohm 1w resistor and 2w zener. Transistor-large heat sink.

CHEAP 'N EASY REGULATOR #4

If higher output current is desired than #3 can supply, use a Darlington transistor. This is simply two transistors in one case; the output of one feeds the input of the other. Because of the two diodes this places between the base and emitter, output will be 1.4 volts lower than the reference voltage. Start with a basic power supply at least 5 volts higher than the regulated output you want.

PREPACKAGED REGULATORS

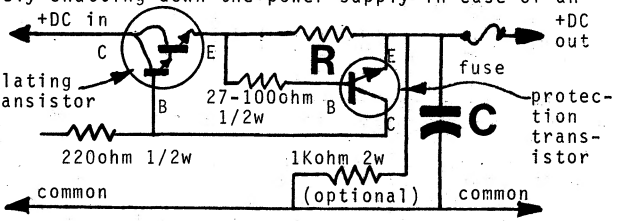


Three-terminal fixed volatage regulators are now replacing custom-built regulators in many applications. They are available in several standard voltages and both positive- and negative-voltage regulators can be bought in several different current ranges. It is not possible to describe in detail the requirements for proper use of these devices, since they are made in a number of different forms by different manufacturers. Some are short-circuit proof; some are not. Some have metal cases which can be grounded directly to the chassis or heat sink; some do not. The only rule to follow is: Study the information that comes with the device. If the manufacturer's spec sheet is available, get it. And do not push the device beyond its specified ratings.

SHORT-PROOFING YOUR VARIABLE POWER SUPPLY

As stated earlier, transistors have very definite current, voltage, and power dissipation limits which must not be exceeded. With darlington transistors, in particular, an accidental overload or short circuit will almost always cause destruction of the transistor. The circuit shown below can be added to any of the regulators thus far described to prevent damage from short circuit or overload conditions. This circuit limits the maximum current which can be drawn by the load. It does not insure, however, that the current and voltage combination across the regulating transistor does not exceed its power rating. For this reason, the shortproofing described should only be relied upon for momentary protection; the best protection is careful use and immediately shutting down the power supply in case of an accidental overload.

CURRENT LIMIT AT	R	C
1/2A	1.5ohm 1/2w	500 mfd
1A	.7ohm 1w	1000 mfd
2A	.33ohm 2w	2000 mfd



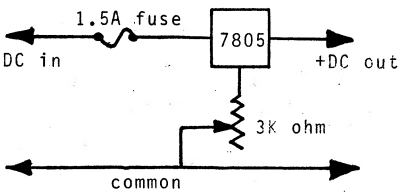
When using this protection circuit on variable power supply #1, add the 220 ohm resistor as shown. The protection circuit can be added to #2 or #3 without modification. (Also, the fixed-voltage regulators #3 and #4 described in vol. 2 may be used with this protection circuit.)

The protection circuit operates by "measuring" the voltage across the added resistor "R" ; this voltage will be proportional to the current through it. When the voltage across this resistor (not to be confused with the regulated output voltage with respect to ground) exceeds the .7 volt inherent barrier voltage between the base and emitter of the protection transistor, current flows into its base. This causes the protection transistor to draw an amplified current through its collector, which has the effect of shorting out the reference drive voltage to the big regulating transistor. (The 27-100 ohm resistor is there to protect the protection transistor from overload. Can't relax for a minute in this business.)

The large capacitor across the output has been added (in the case of variable regulators #3 and #4, it replaces the 500mfd unit) because the resistor "R" in the protection circuit slightly reduces the precision of the regulator's output under varying load conditions. The 1,000 ohm (1Kohm) 2 watt resistor is optional, and may serve no purpose depending on how you intend to use the power supply. It is there because the large output capacitor stores so much energy that it is often convenient, if you want to be able to vary the output voltage rapidly, to have a method of "bleeding off" this charge.

USING THE 7805 FIXED REGULATOR AS A LIMITED-RANGE VARIABLE SUPPLY

Using the circuit shown at right, a 7805 solid-state regulator, which normally puts out a fixed 5 volts, can be made to vary between 5 and 15 volts out. Use of a linear-taper "pot" is recommended. The normal internal short circuit protection of the 7805 does not work well when used this way, so care is needed. Use of a 1.5 amp fuse as shown will give added protection.



HIGHER CURRENT REGULATORS

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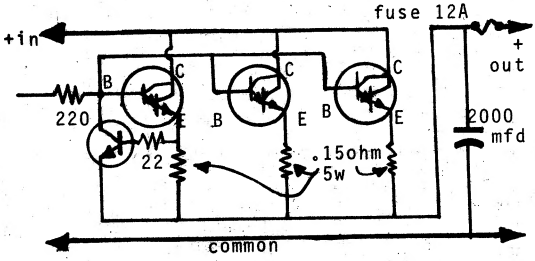

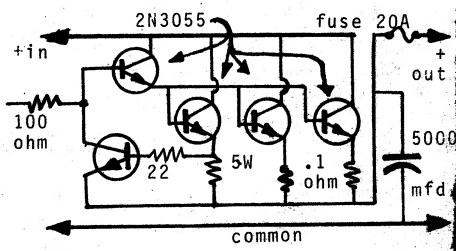

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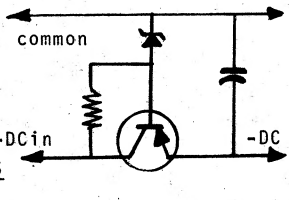

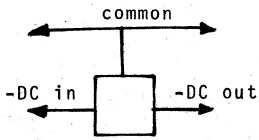

POWER CALCULATIONS

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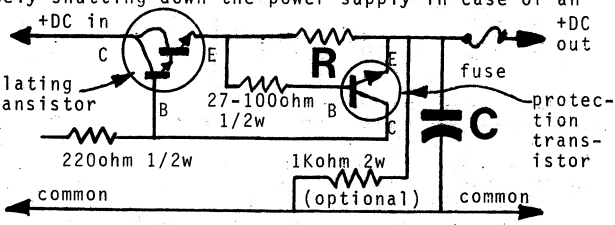
Thus: If you have a basic power source delivering 15 volts to the regulating circuitry, and the regulated output is 10 volts, the regulating transistor is "dropping" 5 volts. If the load circuitry is drawing 1 amp, then the voltage across the transistor is 5 volts, the current through it is 1 amp, and the power it dissipates is 1x5=5 watts. You will need a small heat sink. There you are...just like magic! AE form SL-PS3

SHORT-PROOFING YOUR VARIABLE POWER SUPPLY

As stated earlier, transistors have very definite current, voltage, and power dissipation limits which must not be exceeded. With darlington transistors, in particular, an accidental overload or short circuit will almost always cause destruction of the transistor. The circuit shown below can be added to any of the regulators thus far described to prevent damage from short circuit or overload conditions. This circuit limits the maximum current which can be drawn by the load. It does not insure, however, that the current and voltage combination across the regulating transistor does not exceed its power rating. For this reason, the shortproofing described should only be relied upon for momentary protection; the best protection is careful use and immediately shutting down the power supply in case of an accidental overload.

CURRENT LIMIT AT	R	C
1/2A	1.5ohm 1/2w	500 mfd
1A	.7ohm 1w	1000 mfd
2A	.33ohm 2w	2000 mfd



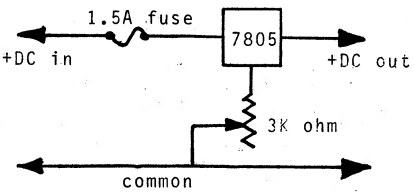
When using this protection circuit on variable power supply #1, add the 220 ohm resistor as shown. The protection circuit can be added to #2 or #3 without modification. (Also, the fixed-voltage regulators #3 and #4 described in vol. 2 may be used with this protection circuit.)

The protection circuit operates by "measuring" the voltage across the added resistor "R" ; this voltage will be proportional to the current through it. When the voltage across this resistor (not to be confused with the regulated output voltage with respect to ground) exceeds the .7 volt inherent barrier voltage between the base and emitter of the protection transistor, current flows into its base. This causes the protection transistor to draw an amplified current through its collector, which has the effect of shorting out the reference drive voltage to the big regulating transistor. (The 27-100 ohm resistor is there to protect the protection transistor from overload. Can't relax for a minute in this business.)

The large capacitor across the output has been added (in the case of variable regulators #3 and #4, it replaces the 500mfd unit) because the resistor "R" in the protection circuit slightly reduces the precision of the regulator's output under varying load conditions. The 1,000 ohm (1Kohm) 2 watt resistor is optional, and may serve no purpose depending on how you intend to use the power supply. It is there because the large output capacitor stores so much energy that it is often convenient, if you want to be able to vary the output voltage rapidly, to have a method of "bleeding off" this charge.

USING THE 7805 FIXED REGULATOR AS A LIMITED-RANGE VARIABLE SUPPLY

Using the circuit shown at right, a 7805 solid-state regulator, which normally puts out a fixed 5 volts, can be made to vary between 5 and 15 volts out. Use of a linear-taper "pot" is recommended. The normal internal short circuit protection of the 7805 does not work well when used this way, so care is needed. Use of a 1.5 amp fuse as shown will give added protection.



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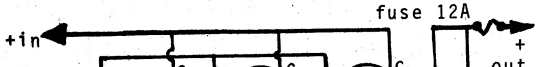

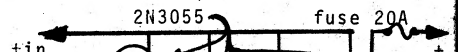

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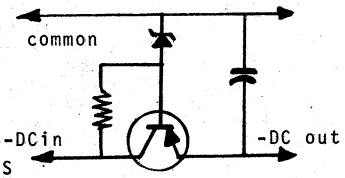

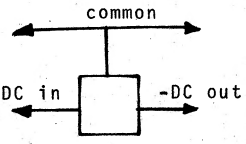

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